BJHS Themes (2024), 1–19
doi:10.1017/bjt.2024.5

RESEARCH ARTICLE

Piecing together 'big pictures' with social network analysis and digital tools

Aleksandra Kaye

Max Planck Institute for the History of Science, Germany
Email: akaye@mpiwg-berlin.mpg.de

Abstract

When considering the 'big picture' in the history of science, what or who is considered important depends upon the focal point of the analysis. Social network analysis, equipped with digital methods, offers historians a way to help generate alternative perspectives for analysis by revealing elusive patterns obscured by the apparent 'centre/periphery' dichotomy or 'great-men' narratives. The presented methods are focused on studying connections, relationships and structural characteristics in networks and can thus help bridge global and local perspectives and suggest new historical lines of argument. This point is illustrated with a case study of Polish oil prospectors working in Argentina in the 1880s, which problematizes the narrative of the formation of transnational networks based on this mineral resource. The article discusses the place of digital methods within historical research, arguing that good skills in the interpretation and communication of outputs produced through digital research methods, coupled with familiarity with their associated theories, strengths and weaknesses, are indispensable.

Who were the nine men in the photograph in Figure 1 and what do their histories mean for the 'big picture' of the history of science?[1] The photograph was taken in 1874 and shows a group of Polish scientific professionals working in Peru at the time. They shared between them expertise in civil engineering, mathematics, geology, topography, architecture and natural history. Most of them stayed in Peru for at least five years, with a couple staying for the rest of their lives. Not pictured in this photograph are the other Poles who were also in Peru in the 1870s, nor the expansive network of acquaintances, friends and family with whom they maintained contact while living and working in Latin America. It is possible to re-create, to a certain degree, the social networks that linked the Poles living and working in scientific professions in Latin America in the nineteenth century. This can be achieved thanks to sources such as the photograph in Figure 1; the letters the migrants sent to their contacts; shared publications; and mentions of two or more Polish migrants together in the same letter, newspaper or periodical article attesting acquaintanceship. It is possible to situate these individuals within a bigger picture, as

1 The author of the photograph is unknown. The photograph is held in the archives of the Polish Academy of Sciences in Warsaw, and it initially appeared in print in Bolesław Orłowski, 'Polscy inżynierowie w Peru', *Młody Technik* (1974) 6(24), pp. 46–58, 48.

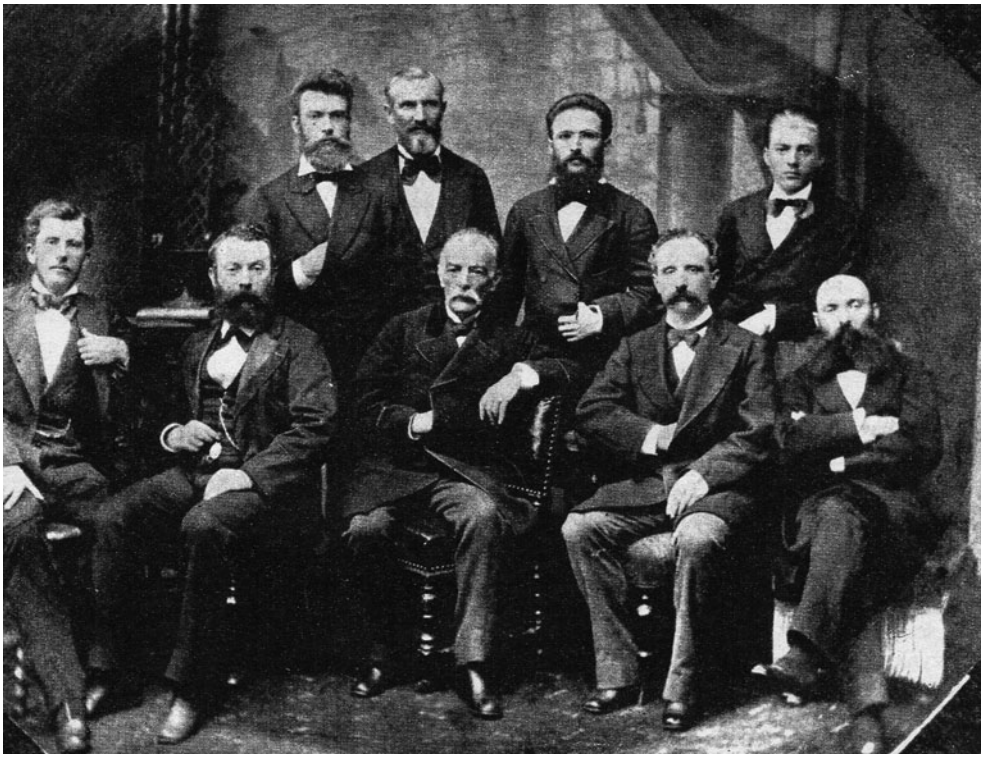

Figure 1. A group of Polish scientific professionals working in Peru. Photograph taken in 1874 in Lima. From the left, standing: Ksawery Wakulski, Aleksander Babiński, Władysław Kluger and Jan Sztolcman. From the left, sitting: Tadeusz Stryjeński, Władysław Folkierski, Ernest Malinowski, Edward Jan Habich and Leonard Laskowski.

evidence indicates that there were active social connections between the Polish people scattered across Latin America as well as with those back in the partitioned territories of the Polish–Lithuanian Commonwealth, and other parts of Europe.

For decades debates have continued among those interested in the history of science and knowledge regarding the perceived tension between the global and the local focus. More recently those engaging in such debates have identified a need for a more polyvocal history of science. These two issues converge on the related question of how best to approach the matter of embracing the hybridity of the ways of knowing, while retaining the coherence of the field.[2] In 1993 James Secord argued that the history of science was dominated by localized case studies, which, while useful for challenging the idea that science was universal, also made it harder to appreciate how knowledge travels, as well as what the 'big pictures' are within the field.[3] Over twenty years later, writing in 2014, Maeve Olohan observed that local case studies still remained dominant in history of

2 For examples from these debates see Carla Nappi, 'The global and beyond: adventures in the local historiographies of science', *Isis* (2013) 104(1), pp. 102–10; Maeve Olohan, 'History of science and history of translation: disciplinary commensurability?', *The Translator* (2014) 20(1), pp. 9–25, 14. See also Problems 7 and 8 in Peter Galison, 'Ten problems in history and philosophy of science', *Isis* (2008) 99(1), pp. 111–24. Similar debates are also taking place within the heritage sector, where museum and archive professionals reflect on how to decolonize their collections. For a recent reflection on the methods used by museums for decentring, increasing inclusivity and improving transparency, see Csilla Ariese and Magdalena Wróblewska, *Practicing Decoloniality in Museums: A Guide with Global Examples*, Amsterdam: Amsterdam University Press, 2022.

3 James A. Secord, 'Introduction', *BJHS* (1993) 26(4), pp. 387–9.

https://doi.org/10.1017/bjt.2024.5 Published online by Cambridge University Press

science.[4] The lack of a sense of the 'big picture' within the history of science was also a subject of discussion at the conference dedicated to this topic held at the University of Warwick in June 2022. Arguably, localized and regional studies still dominate now, but questions of a transnational nature, or those encompassing more extensive regions, attract increased attention.[5] Crucially, the very methods chosen by the historians can contribute towards a better appreciation of the 'big pictures' within history of science. Sujit Sivasundaram, in exploring the 'how-to' of global history of science, has argued that as historians we need to scrutinize not only historiographical terms, but also our methodology and theoretical tools.[6] In this regard, the dynamic discipline of the digital humanities offers a methodological critique and programme useful for historians. It prompts a reconsideration of research methods, as the shift from analogue to digital involves a transition from unstructured to discrete representations, which often highlights the limitations of available sources and missing information. At its core, digital humanities is about getting us to rethink methods.

The article begins with a brief discussion of the current place of digital methods within history, arguing, like Michelle DiMeo and Andrew R. Ruis, that 'historians need not abandon qualitative strategies or traditional research questions in order to embrace new technologies and tools'.[7] The focus is then shifted specifically to social network analysis and its applications to 'big-picture' questions within the history of science. I argue that methods such as social network analysis, especially when implemented digitally, can help historians of science generate alternative perspectives for analysis, and that this can be helpful in revealing elusive patterns obscured by dominant narratives, such as the apparent centre/periphery dichotomy. Examples taken from the study of the knowledge networks of Polish migrants to Latin America between 1830 and 1889 are used to demonstrate how historians of science can apply such techniques to their research.

Digital humanities, digital history and social network analysis

Historians' craft is being transformed by the digital. Our research tools, methods and practices are changing due to the prevalence of digital infrastructure in our professional environment. Historians regularly use the Internet and word-processing programs, make digital presentations, download articles, and take digital photographs in museums, libraries and archives. Many scholars choose to take the engagement with the digital and the application of computational methods to their research materials further. Laurie N. Taylor defined digital humanities as 'the humanities in and for a digital age' – this being one of 817 characterizations collected over five years from participants in the Day of DH workshops.[8] As Claire Brennan pointed out, while digital humanities is by now an established field, with dedicated centres, publications and large-scale conferences,

4 Olohan, op. cit. (2), p. 14.

5 Among others, see James Poskett, *Horizons: A Global History of Science*, London: Viking, 2022; David N. Livingstone, Hugh Richard Slotten and Ronald L. Numbers, *Cambridge History of Science*, vol. 8: *Modern Science in National, Transnational, and Global Context*, Cambridge: Cambridge University Press, 2020, p. viii; Patrick Manning and Abigail Owen, *Knowledge in Translation: Global Patterns of Scientific Exchange, 1000–1800 CE*, Pittsburgh: University of Pittsburgh Press, 2018; Stephanie Zehnle, 'Animal skinners: a transcolonial network and the formation of West African zoology', in Ulrike Kirchberger and Brett M. Bennett (eds.), *Environments of Empire: Networks and Agents of Ecological Change*, Chapel Hill: University of North Carolina Press, 2020.

6 Sujit Sivasundaram, 'Sciences and the global: on methods, questions, and theory', *Isis* (2010) 101(1), pp. 146–58, 157.

7 Michelle DiMeo and Andrew R. Ruis, 'Thinking about sources as data: reflections on epistemic network analysis as a technique for historical research', in Thomas E. Ewing and Katherine Randall (eds.), *Viral Networks: Connecting Digital Humanities and Medical History*, Blacksburg: Virginia Tech Publishing, 2018, pp. 113–35, 127–8.

8 This and other quotes can be found at Jason A. Heppler, 'What is digital humanities?', *What Is Digital Humanities*, 2015, at https://whatisdigitalhumanities.com (accessed 1 April 2023).

https://doi.org/10.1017/bjt.2024.5 Published online by Cambridge University Press

its exact meaning and focus remain the subject of continued debate.[9] Those working in digital history, on the other hand, according to Brennan, focus much more on the pragmatic questions of expanding digital access to historical sources and the new methods of extracting meaning from them.[10] Programmatic differences aside, digital humanities and the related digital history are both enjoying increased acceptance in academia.[11]

Turning primary sources into data sets is a key characteristic of digital history today.[12] Textual sources, images, maps and sources of many other types can be analysed using digital methods. The difficulty lies not so much in the lack of suitable primary sources for digital analysis, but rather, as DiMeo and Ruis point out, in 'learning how to translate the many nuances required in historical research into data that can be processed by computer'.[13] If adequate care is not taken in the process, it is easy, for example, to misinterpret and misrepresent the sources or to lose the finer points of the data. It is worth reiterating here Barbara Bordalejo and Roopika Risam's point regarding the need for the intersectional perspective within digital humanities, that 'biases are often hidden, deeply embedded within the methods subtending scholarly practices, encoded by human actors who have failed to explore how their own biases are translating to the technologies they are designing'.[14] Digital methods, despite their clean outputs, require as much time and critical inquiry from the researcher as non-digital methods. History remains a challenging field for computer science, but, as developments within computational analysis, modelling and visualization methods and tools show, not an impossible one.[15]

As the above hints, the many heterogeneous methods employed in digital humanities do not have to be a closed black box. The newly established *Journal of Digital History* works towards demystifying the digital-history research process by using a new interactive three-layer format of the scholarly article, consisting of the interconnected narrative, hermeneutic and data layers.[16] This allows the reader to understand the what, the why and the how of the research process. The sharing of the data, the rationale behind the method and a step-by-step overview of the process make it possible not only to replicate the study, but also to ask other questions using the data and to apply the method to different sources with ease and confidence. As William G. Thomas III articulated, 'To do digital history … is to create a framework, an ontology, through the technology for people to experience, read, and follow an argument about a historical problem.'[17] Digital-humanities methods naturally have their limitations, just like other research methods. Researcher-introduced biases, gaps in the archives and employing digital methods on partial

9 Claire Brennan, 'Digital humanities, digital methods, digital history, and digital outputs: history writing and the digital revolution', *History Compass* (2018) 16(10), e12492.

10 Brennan, op. cit. (9), p. 9.

11 At the time of writing, the Royal Historical Society was publishing a multi-part blog series dedicated specifically to this subject. See Ian Milligan, 'Historical research in the digital age – part 1: "we are all digital now"', *Historical Transactions Blog*, 30 November 2022, at https://blog.royalhistsoc.org/2022/11/30/we-are-all-digital-now-1 (accessed 2 December 2022). The topic is also addressed in Adam Crymble, *Technology and the Historian: Transformations in the Digital Age*, Champaign: University of Illinois Press, 2021.

12 Luxembourg Centre for Contemporary and Digital History (C^2DH), 'Journal of digital history', *Journal of Digital History*, 2023, at https://journalofdigitalhistory.org (accessed 31 January 2023).

13 DiMeo and Ruis, op. cit. (7), p. 128.

14 Barbara Bordalejo and Roopika Risam, *Intersectionality in Digital Humanities*, York: Arc Humanities Press, 2019, p. 3.

15 For examples of studies illustrating this point see Mats Fridlund, Mila Oiva and Petri Paju, *Digital Histories*, Helsinki: Helsinki University Press, 2020.

16 Luxembourg Centre for Contemporary and Digital History, op. cit. (12).

17 William G. Thomas III, in Daniel J. Cohen, Michael Frisch, Patrick Gallagher, Steven Mintz, Kirsten Sword, William G. Thomas III and William J. Turkel, 'Interchange: the promise of digital history', *Journal of American History* (2008) 95(2), pp. 452–91, 454.

https://doi.org/10.1017/bjt.2024.5 Published online by Cambridge University Press

primary-source material can lead to misleading conclusions. Thus it is advisable to use them alongside other approaches, rather than as the definitive approach, for studying the history of science.

To substantiate the preceding points, I will now focus on just one method which is gaining increased appreciation among digital historians – social network analysis – which I argue is particularly well suited for answering 'big-picture' questions within the history of science.[18] While small-scale social network analysis can be performed qualitatively without digital tools, much of the current research in this area relies on statistical or graph analysis software. There is a significant advantage to using digital methods when conducting social network analysis, particularly in studies dealing with large numbers of historical actors. Digitally implemented social network analysis can be effectively employed to identify important figures or communities of practice that have often been overlooked and hence understudied. Etienne C. Wenger and William M. Snyder define communities of practice as groups of people informally bound together by joint expertise who share their experiences and knowledge.[19] Identified using social network analysis, such communities can be studied to provide new insights into how knowledge is produced and circulated collectively.

There are three main reasons contributing to the suitability of social network analysis for addressing 'big-picture' questions. First, connections are imperative to the methods of social network analysis. Second, social network analysis has a strong hermeneutic function, as representation of social connections as a network structure helps to organize research findings in a way that is verifiable and open to scrutiny. Third, social network analysis approaches account for endeavours that are simultaneously local and global. This helps underline the importance of historical actors at a micro and a macro level – that is, as individuals and as part of the collective. Every individual mapped, with their personal histories, impacts on the overall structure of the network and the big picture of scientific knowledge production.

The idea of using networks to understand the developments of scientific knowledge has a long historiography rooted in sociologically oriented histories of science. In 1923, according to Giovanni Paoloni, 'an editorial in the Polish journal *Nauka Polska* [Polish Science] noted the emergence of a new field of study, consisting of scientific research about science'.[20] In anglophone scholarship, in 1934 Jacob Moreno and Helen Hall Jennings mapped the relationships of girls at New York Training School for Girls in Hudson and analysed their social networks, which according to Martin Grandjean was the first instance of a formal analysis of social networks.[21] Later, in 1963, Derek J. De Solla Price, in *Little Science, Big Science*, 'turn[ed] the tools of science on science itself' in an 'attempt to develop a calculus of scientific manpower, literature, talent, and expenditure on a national and on an international scale'.[22] While De Solla Price focused on

18 According to the recent survey aimed at scholars using network science in their historical research, and conducted by Lea Weiß, Laura von Welczeck and Malte Vogl from the ModelSEN team at the Max Planck Institute for the History of Science, social network analysis methods and concepts are by far the most popular. An article with survey results is forthcoming.

19 Etienne C. Wenger and William M. Snyder, 'Communities of practice: the organizational frontier', *Harvard Business Review* (2000) 78(1), pp. 139–40.

20 Giovanni Paoloni, 'S for scientometrics: or how to analyse and measure scientific production', *Lettera Matematica – International Edition* (2017) 5(2), pp. 179–83, 179.

21 Martin Grandjean, 'Introduction to social network analysis: basics and historical specificities', *HNR+ResHist Conference 2021 – Historical Network Research* (2021), at https://doi.org/10.5281/zenodo.5083036 (accessed 30 January 2023); Jacob Levy Moreno, *Who Shall Survive? A New Approach to the Problem of Human Interrelations*, Washington, DC: Nervous and Mental Disease Publishing Co., 1934.

22 Derek J. de Solla Price, *Little Science, Big Science – and Beyond*, New York: Columbia University Press, 1986, pp. xv–xvi.

https://doi.org/10.1017/bjt.2024.5 Published online by Cambridge University Press

exploring citation networks rather than social networks, his conceptualization of the term 'invisible colleges' came to be influential among scholars interested in circulation of ideas within scientific communities.[23]

Indeed, since the 1960s the question of how new scientific ideas travel has attracted the attention of many social scientists, which led to the development of methods, such as social network analysis, used to quantify and visualize the social structures enabling the movement of, for example, new ideas.[24] These methods are backed by theories, developed, tested and substantiated with evidence by sociologists. Since John F. Padgett and Christopher K. Ansell's influential 1993 paper, in which the authors applied social network analysis to interpret the rise of the Medici family in Renaissance Florence, the method has been gaining purchase among historians.[25] Those who use this sociological method for historical research need to adapt it to make it appropriate for their needs. What differentiates standard social network analysis and its historical variant (sometimes called historical network analysis), according to Melanie Conroy and Kimmo Elo, is that the latter 'must engage with questions of historiography and the use of sources in a way that is different from sociological methods'.[26] That is, in the context of historical networks, the sociological network methods need also to meet the requirements of the traditional hermeneutics of historical research.

As John Edward Terrell has pointed out, social network analysis 'is a set of exploratory techniques for data analysis, not a predetermined view of history programmed into the analyses done by the computational methods employed'.[27] The output of such analysis, just like the outcomes of historical analysis, is contingent on the input – that is, historical sources – and on the interpretation of these as historians tease out 'historical truths' or data points. The analysis starts and ends with archival data: first, information from archives is coded (made readable to the machine), then the coded data are used to create and visualize the network, and finally a return to the archival sources is made to better understand the communities or important individuals detected through the network model. Returning to the primary sources and literature allows the historian using social

23 Price, op. cit. (22), p. 76, defines invisible colleges as groups that 'give each man status in the form of approbation from his peers, they confer prestige, and, above all, they effectively solve a communication crisis by reducing a large group to a small select one of the maximum size that can be handled by interpersonal relationships'. For later works influenced by Price see, for example, Diana Crane, *Invisible Colleges: Diffusion of Knowledge in Scientific Communities*, Chicago: The University of Chicago Press, 1972; Caroline S. Wagner, *The New Invisible College: Science for Development*, Washington, DC: Brookings Institution Press, 2008.

24 The emergence of social network analysis in the 1960s as its own field is often traced to the Harvard Sociology Department and the group of scholars working there with Harrison White. Some key texts on social network analysis include Harrison C. White, *Identity and Control: How Social Formations Emerge*, 2nd edn, Princeton, NJ: Princeton University Press, 2008; Barry Wellman and S.D. Berkowitz (eds.), *Social Structures: A Network Approach*, New York: Cambridge University Press, 1988; Mark S. Granovetter, 'The strength of weak ties', *American Journal of Sociology* (1973) 78(6), pp. 1360–80. For a 'prehistory' of social network analysis, dating to the nineteenth century, see Chapter 2 in Linton C. Freeman, *The Development of Social Network Analysis: A Study in the Sociology of Science*, Vancouver: Empirical Press, 2004.

25 John F. Padgett and Christopher K. Ansell, 'Robust action and the rise of the Medici, 1400–1434', *American Journal of Sociology* (1993) 98(6), pp. 1259–1319. An even earlier, less known example is Michael Alexander and James Danowski, 'Analysis of an ancient network: personal communication and the study of social structure in a past society', *Social Networks* (1990) 12, pp. 313–35. In 2017 there appeared the *Journal of Historical Network Research*, a journal dedicated specifically to the study of networks in their historical contexts.

26 Melanie Conroy and Kimmo Elo, 'Picturing the politics of resistance: using image metadata and historical network analysis to map the East German opposition movement, 1975–1990', in Fridlund, Oiva and Paju, op. cit. (15), pp. 221–35, 225.

27 John Edward Terrell, 'Social network analysis and the practice of history', in Carl Knappet (ed.), *Network Analysis in Archaeology: New Approaches to Regional Interaction*, Oxford: Oxford University Press, 2013, pp. 16–41, 21.

https://doi.org/10.1017/bjt.2024.5 Published online by Cambridge University Press

network analysis to critically reflect on the method and make any necessary adjustments for accuracy.[28]

Among many of its applications, social network analysis can be used by those interested in knowing whether the renowned historical figures to whom much attention and scholarship has been dedicated are really more important to advances in sciences than those who attract less interest. Within social network analysis, the concept of 'centrality' is used to measure this. However, there are many different measures of centrality used to determine who are the most significant individuals in a network – that is, measures of just how crucial certain individuals within the network were for particular purposes – for example for knowledge formation or communication.[29] The network framework facilitates interpreting certain individuals as brokers of knowledge – that is, as defined by Ronald Burt, people who build bridges across structural holes, or in other words those who connect communities and transmit information between them – and examining their role in the formation of sites of collective knowledge making.[30] In this sense, the eponymous go-betweens of Simon Schaffer's edited volume can be understood as brokers of knowledge.[31] It is also possible to determine which individuals were particularly important for group cohesion and for the generation of new ideas. For example, it could be assumed that a node (individual) is important if it is linked to other important nodes. In other words, those individuals who know many influential people are themselves considered influential. Persons who score highly in this measure are important for generating and developing ideas within the group. According to this theory, their ideas would also be influential and more likely to be accepted by others within the group due to the individual's high standing within their immediate community. The study of the position of individuals within the structure of the network also allows us to bring to the fore obscured communities of practice, as will be illustrated in the following section.

Before that, however, let us turn our attention briefly to the potential criticisms of historical social network analysis. We need to recognize that social network analysis always involves an interpretive element, such as what exactly the nodes and edges represent. Social network analysis offers one way to make claims and seek answers about influence and acceptance, or generating ideas, that could also be explained in different ways. The number of data points on which a network is built does not automatically render the resulting analysis reliable. In fact, to the uninitiated, the tidy graphs and visualizations produced using digital methods can indicate greater robustness and completeness of source historical material than is really available. As scholars we make inferences based on assumptions about the world. Mathematical models and statistical tests rely on these assumptions. Hence it is necessary to remain cautious about how modifying these assumptions can affect the results. Various robustness checks and sensitivity analyses have been developed across disciplines, to afford scholars more confidence in the results obtained through quantitative research methods. A good grasp of the digital

28 For a visualization of the 'ideal-typical scheme of the research process, demonstrating the concept of digital hermeneutics', see Figure 1 in Andreas Fickers, Juliane Tatarinov and Tim van der Heijden, 'Digital history and hermeneutics: between theory and practice', in Andreas Fickers and Juliane Tatarinov (eds.), *Digital History and Hermeneutics*, Berlin: De Gruyter Oldenbourg, 2022, pp. 1–20, 10.

29 Two examples are eigenvector centrality (status and prestige within a group) and betweenness centrality (capacity to act as a go-between or broker). For more on these measures see Stanley Wasserman and Katherine Faust, *Social Network Analysis: Methods and Applications*, Cambridge: Cambridge University Press, 1994.

30 Ronald S. Burt, *Brokerage and Closure: An Introduction to Social Capital*, Oxford: Oxford University Press, 2005, p. 18.

31 Simon Schaffer, Lissa Roberts, Kapil Raj and James Delbourgo (eds.), *The Brokered World: Go-Betweens and Global Intelligence, 1770–1820*, Sagamore Beach, MA: Science History Publications, 2009.

https://doi.org/10.1017/bjt.2024.5 Published online by Cambridge University Press

methods employed, including their strengths and weaknesses, is necessary to read the research outputs accurately. Training in the interpretation of social network analysis outputs is therefore key. Further, the observer can only see the elements that the historian has chosen to present in the visualization. Historians are right, then, to remain vigilant about the biases and limitations of the methods and, when they engage with digital methods, to apply the same scrutiny as they would to non-digital methods. According to Ted Underwood, the humanities are defined not just by their subject domains, but by specific sets of qualitative methods.[32] From such an assumption, he continues, quantitative digital methods can be viewed as 'subverting the humanities' true purpose, which is presumably to serve as a counterweight to science'.[33] But as the boundaries between the qualitative and the quantitative, the digital and the analogue, are blurring, digital humanists like Underwood invite us to 'welcome new forms of curiosity about the past'.[34]

How does this look in practice?

To illustrate the ideas already discussed, in this section I will set out how I used social network analysis equipped with digital tools as part of a study into how Polish professionals participated in scientific projects across Latin America in the nineteenth century. This will demonstrate the potential of the method, associated practical concerns and limitations, and how it complements more classical historical research methods. As part of my prior research, I have reconstructed, as far as possible given the constraints of time and available historical sources, the social networks connecting Polish migrants to Latin America with one another and with other persons important to their professional practice for the period between 1830 and 1889.[35] I have then visualized said networks to aid in the examination of the channels of communication the migrants used to collaborate across national borders and across the Atlantic – linking those across Latin America with those in the partitioned territories.[36] Mapping the networks of Polish migrants allowed the study of the structural features – for example, the closely connected groups within the broader community – which in turn enabled the study of the structural positions of specific individuals within it.[37] In other words, it was possible to observe who was connected to whom and how the individuals clustered into communities of practice (referred to as 'groups' or 'modules' in social network analysis). This then aided me in thinking about how the arrangements of the connections between people impacted on how scientific knowledge was formed and how it traveled within and between communities of practice, and in figuring out the most influential figures in those processes.

32 Ted Underwood, 'Dear humanists; fear not the digital revolution: advances in computing will benefit traditional scholarship – not compete with it', *Chronicle of Higher Education* (5 April 2019) 65(29), pp. B15–B17, B15.

33 Underwood, op. cit. (32), p. B16

34 Underwood, op. cit. (32), p. B17.

35 The time frame was selected based on periodization of waves of migration within Polish historiography, to encompass 'Great Emigration' migration (the large-scale emigration of Poles following the November 1830 Uprising, and later failed uprisings), but not the 'Brazilian Fever' migration (the mass migration of Poles to Brazil and Argentina, largely consisting of agricultural workers) that began in earnest in 1889. For more see Aleksandra Kaye, 'Mapping transnational knowledge networks: Polish scientific professionals in Latin America, 1830–1889', PhD thesis, University College London, 2022.

36 There are also some individuals based in North America and other parts of Europe included in the expanded knowledge network, but they account for a tiny proportion of the whole – that is, less than ten people.

37 Although the networks presented here are static, within social network analysis there are methods specifically focused on analysing how the networks change over time, such as temporal social network analysis (TSNA) and dynamic network analysis (DNA). For more on how to use these sorts of network for historical research see Alex Brey, 'Temporal network analysis with R', *Programming Historian*, 4 November 2018, at https://programminghistorian.org/en/lessons/temporal-network-analysis-with-r (accessed 31 January 2023).

https://doi.org/10.1017/bjt.2024.5 Published online by Cambridge University Press

In the networks I reconstructed, I elected to include only 147 migrants, even though I have found evidence of over two hundred Polish professional migrants to Latin America.[38] The migrants I included matched the following criteria: they were figures public enough for there to be records attesting to their presence in Latin America, they were individuals working in skilled professions (jobs that required prior training and/or education), and they were in Latin America for a period of at least a year between 1830 and 1889, inclusive. When selecting whether to include a specific family member or friend, I made the decision on a case-by-case basis, including only those where there was clear evidence of their being involved in the professional lives of the migrants. I was gathering evidence of social connections, of at least acquaintanceship level, between the individuals to include in the network.[39] It is not always obvious which friendships and kinships facilitated the transfer of scientific knowledge; therefore, it is highly likely that more friends and family members could have been included in the network. However, to limit the uncertainty in the network, only those who were overtly involved in the migrants' professional work have been included.

Once I had a list of individuals to be included in the networks, it was necessary to identify who knew whom among these figures, and hence who belonged to the knowledge network. I determined that looking for evidence of collective consciousness among these migrants would not only be difficult but also unnecessary, as many scholars across disciplines, from historian Benedict Anderson to psychologists such as Marilynn B. Brewer and Wendi Gardner, have argued that it is possible for our collective identities to include people we have never met, based simply on some shared attributes, like nationality or occupation.[40] Further, even if the migrants did not articulate a sense of belonging to a particular group, or if the evidence of such self-identification is not available, this does not necessarily negate the existence of a community of practice. The inclusion of the migrants in the knowledge network is, therefore, based on my interpretation of their role, based in turn on the assessment of information from both secondary and primary sources.

The social connections that are the building blocks of communities can be mapped as a network and represented in graph form. To produce a digital graph visualization, a historian can select from an array of programs, or build a network using a programming language such as R or Python. The visualizations in this article have been produced with an open-source program called Gephi, using information about the migrants collected from literature and historical sources and recorded in CSV (comma-separated values) file

38 In the absence of straightforward ways of determining Polish identity on a large scale, at that time when there was no independent Polish state, it was necessary to rely on case-by-case educated approximations, determining Polish identity from a cultural and linguistic perspective. For some scholarship on the manifestations and development of Polish national identity in the nineteenth century see, for example, Tomasz Zarycki, Rafał Smoczyński and Tomasz Warczok, 'Cultural citizenship without state: historical roots of the modern Polish citizenship model', *Theory and Society* (30 October 2021) 51, pp. 269–301; Tomasz Dominik Kamusella, *The Politics of Language and Nationalism in Modern Central Europe*, Basingstoke: Palgrave Macmillan, 2009; James E. Bjork, *Neither German nor Pole: Catholicism and National Indifference in a Central European Borderland*, Ann Arbor: University of Michigan Press, 2008; Timothy Snyder, *The Reconstruction of Nations: Poland, Ukraine, Lithuania, Belarus, 1569–1999*, New Haven, CT: Yale University Press, 2003. On indifference in relation to Eastern European national identity see Tara Zahra, 'Imagined noncommunities: national indifference as a category of analysis', *Slavic Review* (2010) 69(1), pp. 93–119.

39 I define acquaintanceship as existing between two people if there is evidence of their meeting one another in person or of their having corresponded.

40 Benedict Anderson, *Imagined Communities: Reflections on the Origin and Spread of Nationalism*, revised edn, London: Verso, 2006; Marilynn B. Brewer and Wendi Gardner, 'Who is this "we"? Levels of collective identity and self representations', *Journal of Personality and Social Psychology* (1996) 71(1), pp. 83–93.

https://doi.org/10.1017/bjt.2024.5 Published online by Cambridge University Press

format.[41] The most basic information necessary to produce a social network graph is a list of nodes – here this is a list of migrants and their acquaintances – and an edge list – in this case a list of who knew whom. To begin with I have produced a visualization that shows the connections between just the Poles in Latin America (Figure 2), and then, second, an expanded version showing connections between Poles and others in their communities of practice (Figure 3).[42] To emphasize, the visualizations record social connections, not spatial ones. I wanted to get a broad overview and idea of the structure of the network based on the connections I found evidence for in the primary and secondary sources for the entirety of the study period; that is, from 1830 to 1889. Even though the networks would change and look different over time as people joined it or left (died, severed relationships or otherwise separated themselves from the group), the information and knowledge in these networks would remain, and could be transferred at different times through the connections mapped.

Within the Polish-only networks there are several different connected components – that is, groups for which nodes are directly or indirectly linked. Specifically, in the Polish-only network there are two big distinct clusters, one triad, three dyads and sixty-three unconnected individuals. The broader network encompassing the Poles and others is visibly more interconnected and there are fewer nodes with no connections. There are twenty-nine connected components of two or more nodes and only thirty-two nodes with no ascertained connections. It is not possible that the unconnected individuals did not have any acquaintances; rather, this is a reflection of gaps in knowledge about these people, resulting from limited information about them in sources and historiography. Among the connected nodes the two biggest components have 195 and ninety-four members. For these connected individuals the information is more complete and we can be more confident about the extent of their social connections. What the most complete section of the network indicates is that, theoretically, information from any one of the 195 individuals could have reached all the other 194 people via personal channels of communication, like word of mouth.

Within this network some groups of people were more interconnected than others, which suggests that they were likely to have formed a community of practice and worked closely together. The 'modularity' measure can be used to determine mathematically these tightly knit groups. The modularity of a network refers to how well it can be divided or separated into smaller, more cohesive groups or modules. The popular Louvain method is one of the procedures available for determining communities within networks by finding a partition (a set of communities) with high modularity.[43] A partition's modularity is defined as 'a scalar value between −1 and 1 that measures the density of links inside communities as compared to links between communities'.[44] To determine each community, the Louvain algorithm first assigns each node to its own community; it then goes through all the individual nodes and attempts to place each in the community of a neighbouring node, every time recording the modularity value resulting from such a placement. Each node is placed in a community which increases the modularity of the partition by the highest amount or is left in its own community if moving it does not increase modularity. Second, a new network is created using the communities from the first stage as nodes, to

41 To learn more about Gephi and/or to download the free software see Mathieu Bastian, Sebastien Heymann and Mathieu Jacomy, 'Gephi: an open source software for exploring and manipulating networks', *International AAAI Conference on Weblogs and Social Media* (2009), at https://gephi.org (accessed 1 April 2023).

42 All visualizations are available in full resolution in the online publication of this issue.

43 Vincent D. Blondel, Jean-Loup Guillaume, Renaud Lambiotte and Etienne Lefebvre, 'Fast unfolding of communities in large networks', *Journal of Statistical Mechanics: Theory and Experiment* (2008) 2008(10), P10008, at https://doi.org/10.1088/1742-5468/2008/10/P10008 (accessed 1 April 2023).

44 Blondel *et al.*, op. cit. (43), p. 2.

https://doi.org/10.1017/bjt.2024.5 Published online by Cambridge University Press

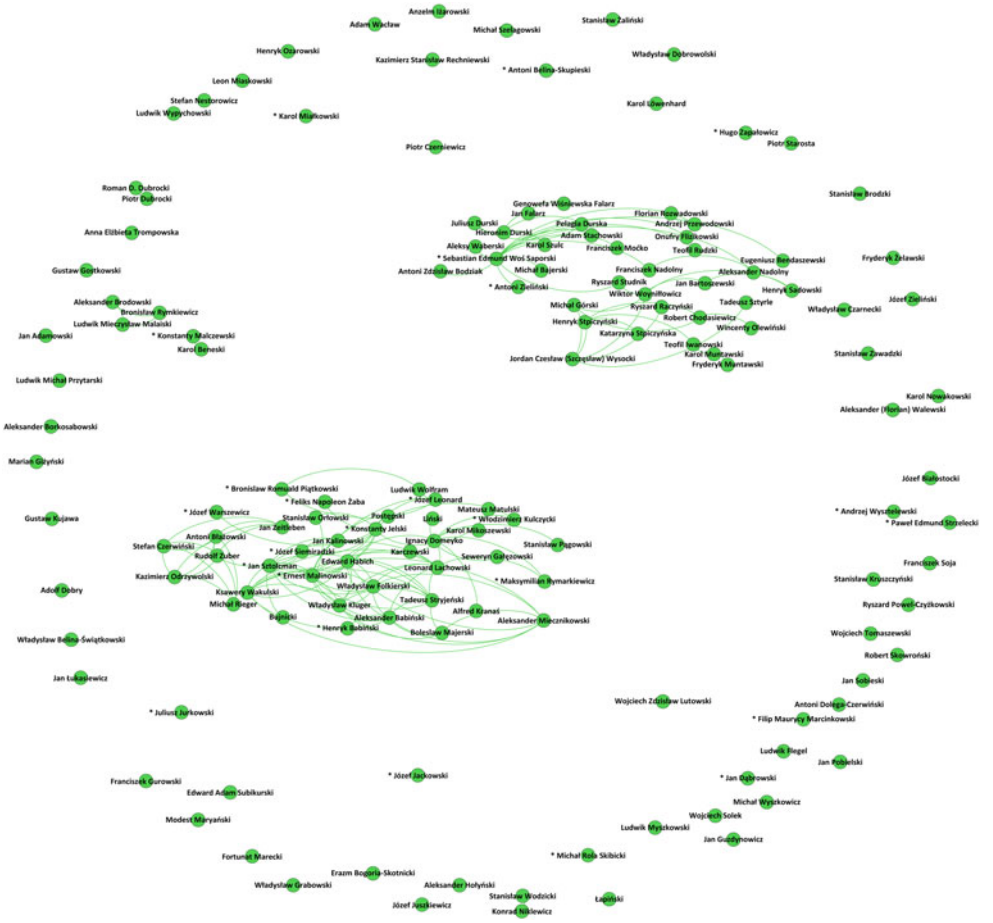

Figure 2. Network mapping connections between Polish migrants in Latin America, 1830–89. Copyright A. Kaye.

which the first step can then be applied again. These two steps are repeated until there is no possible increase in modularity by moving 'nodes' (the currently identified communities) into new communities. In essence, the algorithm merges communities to increase modularity until merging them does not result in any further increase in modularity. Then, 'the communities found are aggregated to build a new network of communities'.[45] The modularity measure of this final partition is used as the modularity measure of the overall network. I have run the modularity calculations on the Polish-only and the expanded networks (illustrated by Figures 2 and 3) and then used the results to colour-code the different communities in Figures 4 and 5. The closer the modularity is to 1 the more likely the individuals in the network were in fact in communities proposed through the algorithm, and for the Polish-only network the modularity value is 0.654. This number suggests that Polish migrants formed close-knit communities within their knowledge networks. Further, it is also possible to use modularity to calculate the likely impact of different factors on division into communities, such as professional affiliation, geographical location or another feature chosen by the historian.

45 Blondel *et al.*, op. cit. (43), p. 5.

https://doi.org/10.1017/bjt.2024.5 Published online by Cambridge University Press

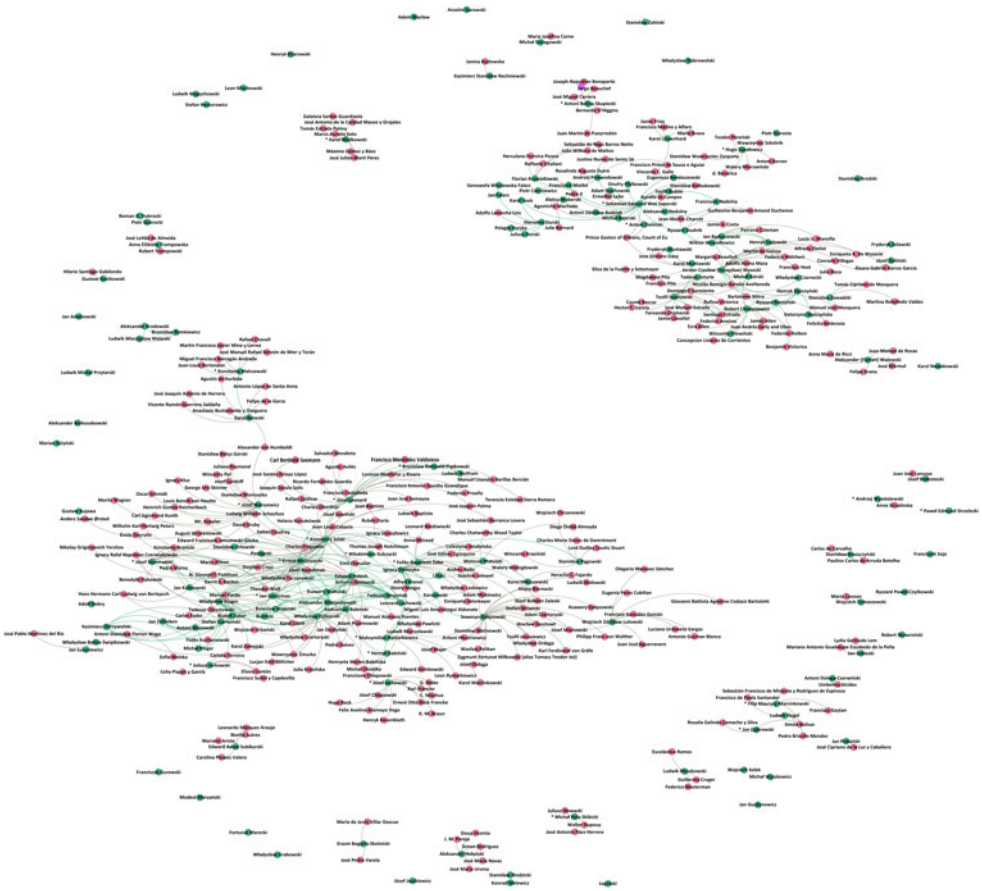

Figure 3. Network mapping connections between Polish migrants and others in Latin America, 1830–89. Green represents Polish people in Latin America and pink represents everyone else. Copyright A. Kaye.

Figures 4 and 5 illustrate the communities that emerged using the modularity measure. I inspected these communities to see whether the quantitatively derived findings would be corroborated by qualitative research – to check that the algorithm had not gone awry. To do so, I returned to primary sources to assess the extent of collaborations and exchanges of knowledge, such as joint projects and publications by the people in the specified communities, validating that the people in the communities determined algorithmically not only knew each other personally but also regularly collaborated professionally. It is noteworthy to point out that most of the connections I identified were between those from Latin America and the partitioned territories. While this might seem obvious given the subject of my investigation, what it highlights is that those in marginalized regions did not necessarily rely on those in North America and Western Europe for scientific collaborations.

Further, by using the network method, some communities that had previously been concealed came to the fore. In particular, a case study of Polish oil engineers serves to highlight how historical understanding can be deepened by a combination of quantitative and qualitative methods. In the following section, I will explore how the network approach led to identifying a true community of practice substantiated by close reading

https://doi.org/10.1017/bjt.2024.5 Published online by Cambridge University Press

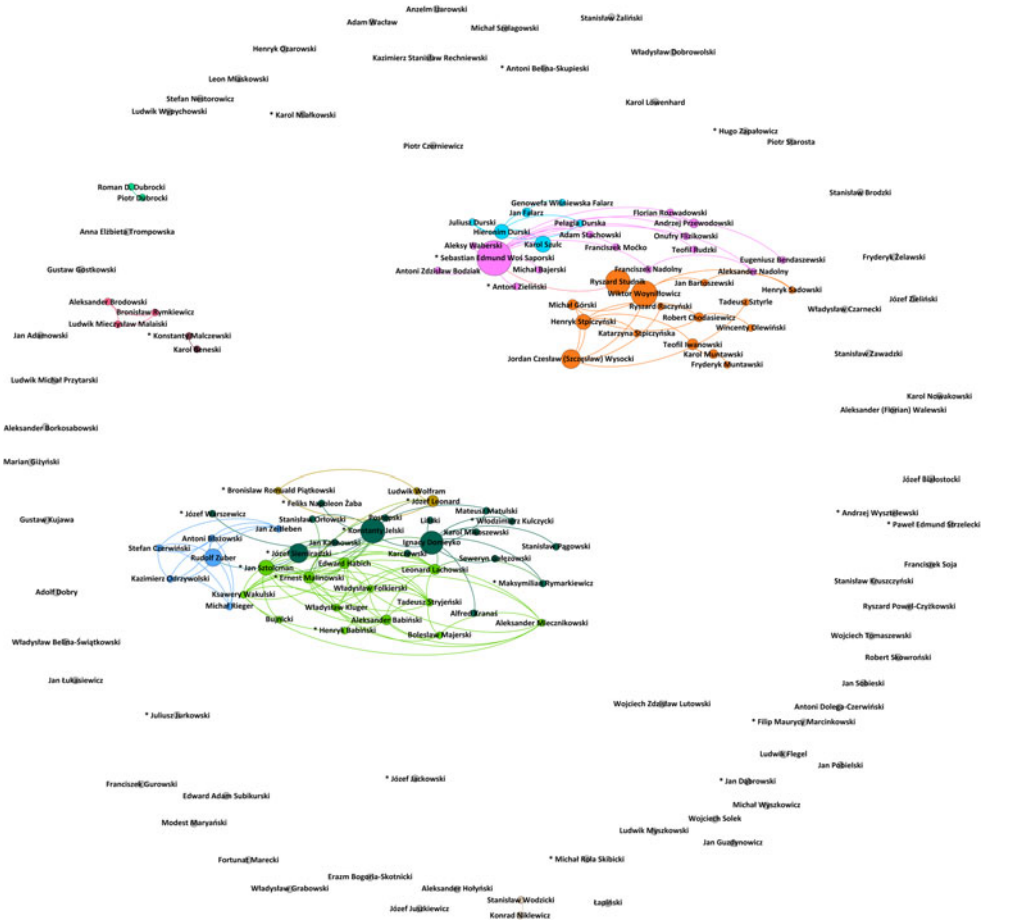

Figure 4. The Polish-only knowledge network (by modularity) – a variation of the network-mapping connections between Polish migrants in Latin America, 1830–89. The colours of the nodes represent an individual's belonging to different communities as determined by applying the Louvain algorithm. The size of the node indicates its influence on community cohesion – the bigger the node, the higher its eigenvector-centrality score. Copyright A. Kaye.

of published accounts produced by the historical actors in question. This dual approach showed evidence for both knowledge transfer from Argentina to Galicia, and the broader generation of knowledge related to petroleum prospecting. This case study illustrates further how collecting historical data needed for network analysis highlights the limitations of the methodology used, particularly the absence of a complete network. However, I argue that this method has the potential to open up avenues for deeper and more nuanced exploration within a particular research domain, in this case critically examining and questioning the challenges and issues related to the development of transnational networks specifically connected to mining resources.

Locating obscured communities of practice: Polish oil professionals in Argentina

Referring to Figure 5, there is a small community, made of just eight nodes coloured in navy blue, at the left bottom corner of the main big cluster. That community, upon closer

https://doi.org/10.1017/bjt.2024.5 Published online by Cambridge University Press

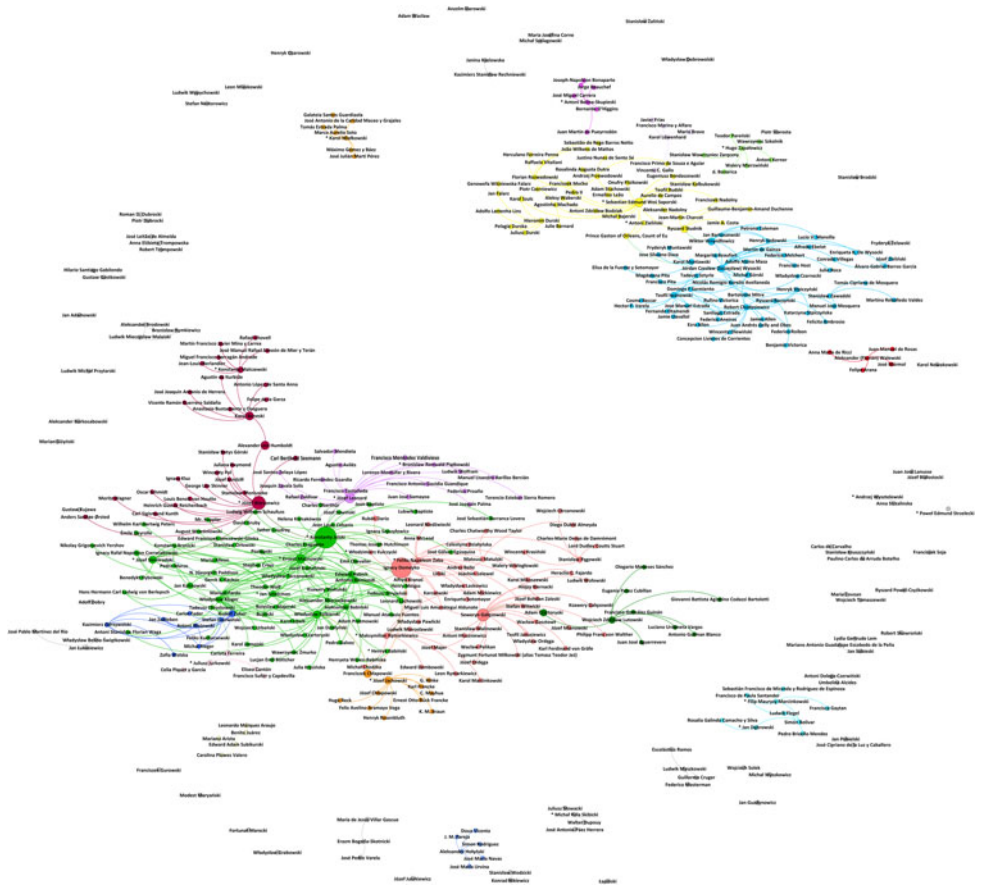

Figure 5. The expanded Polish knowledge network (by modularity) – a variation of the network-mapping connections between Polish migrants and others in Latin America, 1830–89. The colours of the nodes represent individuals belonging to different communities as determined through the application of the Louvain algorithm. The sizes of the nodes indicate their influence on community cohesion – the bigger the node, the higher its eigenvector-centrality score. Copyright A. Kaye.

inspection, turned out to consist principally of Polish oil professionals working in Argentina. Among these individuals Rudolf Zuber arrived first. He had a strongly established career in the Austrian partition of the Polish–Lithuanian Commonwealth, working as a docent in geology at Uniwersytet Lwowski (Lviv University) before he set out to look for petroleum deposits in Argentina in 1886. Oil deposits in the northern Carpathian mountains in Galicia were plentiful and, locally, have been intensely studied. The Bóbrka oil mine, which opened in 1854, was amongst the first modern oil mines in the world, and the location of the first petroleum extraction company.[46] Yet, according to Alison Fleig Frank, the history of Galician oil production is one of oil pioneers and entrepreneurs, which nonetheless to this day remains little studied.[47] The role of Polish

46 Piotr Krzywiec, 'The birth and development of the oil and gas industry in the northern Carpathians (up until 1939)', *Geological Society, London, Special Publications* (2018) 465, pp. 165–89.

47 Alison Fleig Frank, *Oil Empire: Visions of Prosperity in Austrian Galicia*, Cambridge, MA: Harvard University Press, 2007, pp. 4, 7; see also the more recent Piotr Franaszek, Paweł Grata, Anna Kozicka-Kołaczkowska,

https://doi.org/10.1017/bjt.2024.5 Published online by Cambridge University Press

engineers from Galicia in the early stages of the oil industry in Latin America has received yet less attention.

Zuber was contracted by Carlos Fader, a German living in Argentina from 1868, as the technical and administrative director of the Compañía Mendocina de Petróleo (Mendoza Oil Company), when the two met during Fader's visit to the oil mines in the northern Carpathian mountains. Once in Latin America, Zuber went about mapping bituminous coal deposits in the Andes, visiting also Bolivia and Chile for these purposes, and published his findings in Spanish in the Argentinian professional publication *Boletin de la Academia Nacional de Ciencias en Córdoba* (Bulletin of the Academy of Sciences in Cordoba), and in the Polish popular magazine *Kosmos* (The Cosmos) and in *Rozprawy* (Trials), the academic journal associated with the Faculty of Mathematics and Natural Sciences of the Polska Akademia Umiejętności (Polish Academy of Learning).[48] Just a few years after the well-known commercial oil wells were opened in Titusville in the United States in 1859, Argentina began drilling for oil from 1865, and, according to Daniel Barneda, began developing local expertise.[49] The Mendoza Oil Company, which opened in April 1886, is often noted as the first Argentinian oil company to gain commercial success and longevity.

Fader, as well as employing the twenty-eight-year-old Zuber, also hired a number of other young Polish engineers: Kazimierz Odrzywolski (who came with his wife Zofia Wolska), Antoni Błażowski, Michał Rieger, and later Stefan Czerwiński and Jan Zeitleben and six other Polish workers.[50] Together they formed the community marked out in the network. These Poles, further to bringing their expertise, also took with them equipment such as the Polish–Canadian drilling derricks from Galicia, and used those to drill for oil deposits in Argentina.[51]

It is possible to expand the network method to include other factors that influence knowledge production, circulation and acceptance, such as material culture, infrastructure and semantic meaning. For example, the framework of socio-epistemic networks, as defined by scholars at the Max Planck Institute for the History of Science, considers knowledge networks to be composed of three different layers: the social network, the semiotic network (also known as the material network) and the semantic network.[52]

Mariusz Ruszel and Grzegorz Zamoyski, *A Prometheus on a Human Scale: Ignacy Łukasiewicz* (tr. Robin Gill), Bern: Peter Lang International Academic Publishers, 2019.

48 Rudolf Starzewski, 'Rudolf Zuber', *Czas: Dziennik polityczny i literacko-społeczny* (1920) 112, pp. 1–4, 3; Rodolfo Zuber, 'Informe sobre el petróleo de la laguna de la Brea (provincia de Jujuy, República Argentina)', *Boletin de la Academia Nacional de Ciencias en Córdoba, República Argentina* (1887) 10, pp. 442–7; Zuber, 'Estudio geológico del Cerro de Cacheuta y sus contornos (República Argentina – provincia Mendoza)', *Boletin de la Academia Nacional de Ciencias en Córdoba, República Argentina* (1887) 10, pp. 448–72.

49 Marcelo R. Yrigoyen, 'Reseña sobre los conocimientos y la explotación de los hidrocarburos en Argentina antes de 1907', *Petrotecnia: Revista del Instituto Argentino del Petróleo y del Gas* (February 2007) 48(1), pp. 16–36; Daniel Barneda, 'La Compañía Mendocina de Petróleo y la explotación del Yacimiento Cacheuta', *Petrotecnia: Revista del Instituto Argentino del Petróleo y del Gas* (April 2007) 48(2), pp. 10–11, 10.

50 Jan Zeitleben, '"Nowa Polonia" w dziewiczych lasach południowej Ameryki (z ilustracjami podług fotografij zdjętych przez Dra Zubera)', *Nafta: Organ Towarzystwa techników naftowych we Lwowie* (1 January 1895) 3(1), pp. 5–8, 6.

51 Franaszek *et al*., op. cit. (47), pp. 217–18, 251.

52 Jürgen Renn, Dirk Wintergrün, Roberto Lalli, Manfred Laubichler and Matteo Valleriani, 'Netzwerke als Wissensspeicher', in Jürgen Mittelstraß and Ulrich Rüdiger (eds.), *Die Zukunft der Wissensspeicher: Forschen, Sammeln und Vermitteln im 21. Jahrhundert*, Munich: UVK Verlagsgesellschaft Konstanz, 2016, pp. 35–79; Roberto Lalli, Riaz Howey and Dirk Wintergrün, 'The socio-epistemic networks of general relativity, 1925–1970', in Alexander S. Blum, Roberto Lalli and Jürgen Renn (eds.), *The Renaissance of General Relativity in Context*, Cham: Springer International Publishing, 2020, pp. 15–84; ModelSEN Project, 'Theory', *Socio-epistemic Networks: Modelling Historical Knowledge Processes* (2021), at https://modelsen.mpiwg-berlin.mpg.de/theory (accessed 1 April 2023).

https://doi.org/10.1017/bjt.2024.5 Published online by Cambridge University Press

Here, however, only the social layer is analysed. Most of these migrants only stayed in Argentina for a couple of years; nonetheless the involvement of Poles in Argentinian oil extraction at that time was substantial enough to result in one of the oil fields in Jujuy near the Argentine border with Bolivia being named Nueva Polonia (New Poland), as seen in Figure 6.[53]

Despite the name, the community working at Nueva Polonia was truly transnational. In 1895, Zeitleben, one of the oil engineers who worked in Argentina, recalled on the pages of the Lviv periodical *Nafta: Organ Towarzystwa techników naftowych we Lwowie* (Petroleum: The Organ of the Association of Petroleum Technicians in Lviv), that the 'forty-something inhabitants of Nueva Polonia represented 11 nations that communicated using 7 languages. It was a true Tower of Babel'.[54] While the exact nationalities are not listed by Zeitleben, it is clear from the rest of the article that the Poles and Argentinians formed a majority among this group of people. Figure 5 illustrates how this community fitted within the broader Polish knowledge networks in Latin America. By comparing the network in Figure 5 with the information in Zeitleben's article and its accompanying photograph (Figure 6), it can be noted that more historical figures should be incorporated into the network.[55] Historians interpret and connect information from primary and secondary sources to produce plausible historical narratives, using their own subject knowledge and judgement to craft convincing and accurate historical arguments. If the information found in the sources does not support an expected hypothesis, it is necessary to ask why that is, to conduct further research and perhaps to change the line of argumentation. The same reflection is essential when analysing research findings obtained through digital methods. With the aim of producing robust research outputs, using social network analysis alongside other research methods is preferable to seeing it as the sole, definitive method. The comment about the international nature of the group working at Nueva Polonia, in particular, suggests that more connections existed than are mapped in my network, which in turn points towards a direction for future research – overlooked early periphery-to-periphery cooperation and how that fit into the wider international development of the oil industry.

What is further noteworthy with regard to networking among the Polish oil professionals in Argentina, is that there is an indication that these engineers saw themselves as a sort of community, not only while working in Latin America and establishing a mining settlement named after their motherland, but also upon their return to Galicia. In an 1894 eulogy of Błażowski, Zuber recounted that the former wanted to unite and organize the Polish workers in the oil industry in Galicia, who typically were a dispersed group.[56] According to Zuber, Błażowski 'in this effort was supported, among many others, above all by his [Latin] American colleagues, Dr Zuber who returned to the country in July 1892 and Odrzywolski, who returned at the beginning of 1893'.[57] The ties and a sense of professional community were important to these migrants regardless of location.

53 Zeitleben, op. cit. (50), p. 6. Nueva Polonia was short-lived, however, as it proved to be an inhospitable place.

54 Jan Zeitleben, '"Nowa Polonia" w dziewiczych lasach południowej Ameryki (z ilustracjami podług fotografij zdjętych przez Dra Zubera) (Dokończenie)', *Nafta: Organ Towarzystwa techników naftowych we Lwowie* (28 February 1895) 3(4), pp. 30–2 and Tab. II–III, 31. All translations from Polish into English in this article, unless otherwise stated, are the author's own.

55 Photograph taken by Rudolf Zuber in 1891. It first appeared in print accompanying Zeitleben, op. cit. (54), Tab. II.

56 Rudolf Zuber, 'Antoni Błażowski (dokończenie)', *Nafta: Czasopismo poświęcone interesom górnictwa i przemysłu naftowego i wosku ziemnego* (1894) 2(4), pp. 51–3, 52.

57 Zuber, op. cit. (56), p. 52.

https://doi.org/10.1017/bjt.2024.5 Published online by Cambridge University Press

Figure 6. Photograph from Nueva Polonia, taken by Rudolf Zuber in 1891. It was one of six that originally accompanied Jan Zeitleben's article series, which appeared over four issues of *Nafta* in January and February of 1895. The original caption read (in translation), '"Nueva Polonia" and her inhabitants'.

During his six years in Latin America, Zuber kept in contact with colleagues, and reminded those who remained in Galicia of his work through publications and visits. On 25 October 1887, when visiting Galicia, Zuber gave a lecture at the meeting of the Towarzystwo Przyrodników im. Kopernika we Lwowie (Copernicus Society of Naturalists in Lviv), about his time in Latin America and about the search for, and later extraction of, oil in Argentina. The lecture, transcribed later on the pages of the periodical *Kosmos*, ended with a promise of a richly illustrated book, based on Zuber's photographs and accounts, and a number of academic publications to be produced with the help of two Polish geologists based in Kraków: Dr Feliks Kreutz and Dr Władysław Szajnocha.[58] Zuber clearly had plans to share the knowledge he gained in Latin America with a Polish readership. According to fellow engineer Zeitleben, Zuber went back to Galicia in 1892 to 'use his knowledge and expertise gained [in Argentina] for the purposes of [Poland]'.[59] He returned with expanded professional experience from his time working in Latin America, and substantial geological and mineralogical collections, which he donated to universities in Kraków and Lviv.[60]

The fact that Zuber and other oil experts went on to use the professional experience they gained in Argentina in their work back in Poland illustrates that the exchange of knowledge and expertise was important for the development of the oil industry, and of

58 Rudolf Zuber, 'Z podróży do Południowej Ameryki', *Kosmos* (1887) 12, pp. 409–14.
59 Zeitleben, op. cit. (50), p. 6.
60 Starzewski, op. cit. (48), p. 3.

https://doi.org/10.1017/bjt.2024.5 Published online by Cambridge University Press

geology more broadly, in both regions. The experience and knowledge Zuber gained in Latin America stayed with him as he resumed his professional practice in Galicia. In his 1894 lecture on the future of geology in Poland, presented to the naturalists' society in Lviv, Zuber argued that theoretical geological knowledge could inform practical mining and engineering projects.[61] The accounts of the things he saw and did while working abroad, in Latin America and later in other parts of the world, served him as teaching tools shaping the next generations of Polish geologists. Professor Julian Tokarski, a former student of Zuber's, recounted in 1950 that his academic mentor

> had great enthusiasm for delivering lectures, which were always characterized by *świetna forma* [great style] and were richly illustrated with specimens and slides, which often came from the professor's distant journeys. He liked to talk about them [his journeys], often inserting anecdotes; he was a master storyteller.[62]

The experiences he had in Latin America evidently left a lasting impression on Zuber and shaped his scientific practice.

As this case study of Polish oil professionals working in Latin America indicates, there is merit in the network methodology as it highlights communities of practice that could have otherwise been overlooked, but which nonetheless were important for the advancement of scientific disciplines. In combination with archival research and other methods, social network analysis can be used to explore big-picture questions, such as the transnational development of the petroleum industry. It should be noted that Argentina and Poland, both marginalized spaces, collaborated in pioneering the development of oil production. It was only later that this industry came to be dominated by the United States and the Russian Empire.

Conclusion

Often in the histories of scientific progress the focus is placed on prominent individuals, but construction of scientific knowledge is a collective process. Social network mapping is a useful method for directing attention to the connections between people and considering the collective aspect of knowledge production and presenting circulation as something generative and constructive. This is in line with the general move within the history of knowledge, and the history of science, away from narratives of extraordinary individuals advancing knowledge in near isolation. The focus on a specific group of people and the network of connections between them and others allows for a different, intermediate framing, oscillating between the local and global. It accounts both for individuals at a micro scale and for the macro themes of how these connected individuals fitted into the transnational community of science practitioners. The majority of the connections that I found were periphery-to-periphery connections between the migrants and those in their proximity and in different parts of Latin America, followed by connections across the Atlantic with those in the partitioned territories, and to people in other parts of the world. The knowledge networks model of conceptualizing scientific co-production, as well as being helpful in navigating the local–global scale, shifts the focus onto the productive connections that might have otherwise been omitted from analysis, such as the

61 Rudolf Zuber, 'O praktycznych zastósowaniach geologii: Odczyt dra Rudolfa Zubera wygłoszony na XXIII. walnem zgromadzeniu towarzystwa przyrodników im. Kopernika we Lwowie d. 19 lutego 1894', *Kosmos* (1894) 19, pp. 13–25.

62 Julian Tokarski as quoted in Jerzy B. Miecznik, 'Profesor Rudolf Zuber: ojciec polskiej geologii naftowej', *Przegląd Geologiczny* (2021) 69(8), pp. 528–39, 536.

https://doi.org/10.1017/bjt.2024.5 Published online by Cambridge University Press

community of oil professionals from Galicia working in Argentina in the 1880s. Social network analysis, aided by digital tools, therefore, provides a means to make meaningful connections between the 'big picture' and individual case studies.

Acknowledgements. I would like to thank Emily Erikson and Nicola Miller for their invaluable comments on earlier drafts of the material that became this article. I am also grateful to all the members of the ModelSEN team for sharing their knowledge and expertise with me, and to James Poskett for inviting me to the History of Science and the 'Big Picture' conference, and for the enthusiasm he showed for this article. I am appreciative of the two anonymous reviewers for their insights.

Cite this article: Kaye A (2024). Piecing together 'big pictures' with social network analysis and digital tools. *BJHS Themes* 1–19. https://doi.org/10.1017/bjt.2024.5